HIGH FREQUENCY ULTRASONIC EQUIPMENT FOR DETECTION OF SUBMILLIMETER FLAWS

U. Opara

Krautkrämer GmbH

Hürth, FRG

INTRODUCTION

At the present, new materials with mechanical properties superior to steel are introduced into the design of advanced technical products. One class is fine ceramics, which have high strength, low weight, and good thermal behavior and are therefore ideal materials for turbine parts, automotive components, and machine tools.

For quality control of these parts, ultrasonic inspection seems to be one of the major methods. In the following table some material properties, which are relevant for ultrasound, are compared with steel:

	Ceramic	Steel
σ N/mm²	700	500-700
ρ g/cm³	3.2	7.9
Typ. grain size µ	1...5	10....100
C_1 mm/µsec	11..12	5.9
α/10 MHz dB/mm	0.03	0.1

where σ is the strength, ρ the density, C_1 the sound velocity of longitudinal waves, and α the absorption coefficient for ultrasonic waves.

Since ultrasonic scattering obeys scaling laws, flaw detection in ceramics is comparable with flaw detection in steel provided the geometrical sizes in relation to the wave lengths are equal. Typical of the sound velocity in ceramics is a factor increased by two, therefore the test frequency must be doubled to get the same flaw detectability compared to steel. Regarding fracture mechanics, the demand is that the typical flaw size, which has to be detected, is approximately 10 microns. This is due to the brittleness of fine ceramics, whereby small inclusions of this size can become a critical flaw.

To summarize: For nondestructive testing of technical ceramics, on the one hand, higher frequencies have to be used which seemed to be no problem

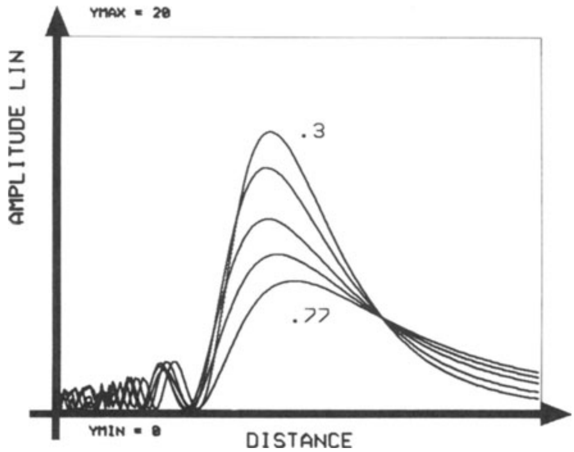

Fig. 1 Sensitivity versus distance (parameter focusing factor)

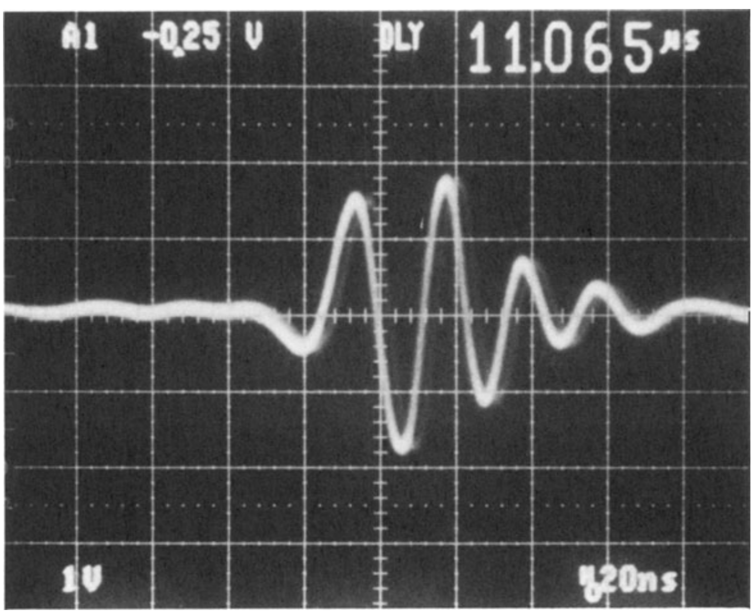

Fig. 2 50 MHz transducer echo

due to the low absorption in the material; on the other hand, a high detection sensitivity is necessary due to fracture mechanics demands.

HOW TO ACHIEVE HIGH DETECTION SENSITIVITY

One way to achieve high detection sensitivity is to improve the S/N ratio of the electronics and to look for a high coupling factor in the ultrasonic generator but this gives only a limited improvement in the sensitivity. Another way is to use focused transducers.

There are two limitations in the use of focused transducers: Due to the high difference in sound velocity between water and fine ceramics only small incident angles to the surface are allowed. With angles greater than 8° no longitudinal ultrasonic wave penetrates the ceramic part. The use of a simple spherically shaped transducer limits the D/R ratio, which is the ratio between the transducer diameter and the focal radius, to values smaller than .3.

The usable length of the focus varies as F^2, whereby F is the focusing factor. A small value of F means a small focal cross section and therefore a high sensitivity. On the other hand, the usable length where this sensitivity can be exploited, decreases rapidly and for a volumetric scan of the test sample additional runs are necessary.

In Fig. 1, different combinations of the focusing factor and transducer diameter are investigated to obtain a long focal length but with guaranteed sensitivity at a predetermined depth.

On these considerations, the ultrasonic frequency is only important as a scaling factor. The higher the frequency selection, the deeper the sound penetration into the material.

As a first step we selected the following parameters:

Frequency	50 MHz
Transducer diameter	2/16 inch
Radius, i.e. focal length in water	1 inch

This gives a D/R ratio of .12, therefore no surface wave generation should disturb the flaw detection. The focus strength of .33, which is a moderate value, leads to a focal length of 2.2 mm at a depth of 3.5 mm, assuming that fine ceramics are concerned. By using these focusing parameters we gain 20 dB sensitivity compared to an unfocused transducer.

The transducers in Fig. 2 were made of PVDF, a plastic material with a lower coupling coefficient than the normally used piezo-materials but with better matching to water. The net effect is a sensitivity loss of approximately 8 dB compared to piezo-materials.

The transducers have been operated with the USH 100 System which can operate transducers up to 100 MHz. With this system we received backwall echoes 30 dB above the noise level when using fine ceramic test samples. By this measurement and other tests we are now sure to have a sensitivity for the detection of flaws which are equivalent to 10μ flat bottom holes.

HOW TO OPERATE A 100 MHZ SYSTEM IN A SIMPLE WAY

If a high frequency transducer is operated with a standard flaw detector, the upper band pass of this flaw detector will cut down all high frequency components and pass only the low frequency part. The sound field

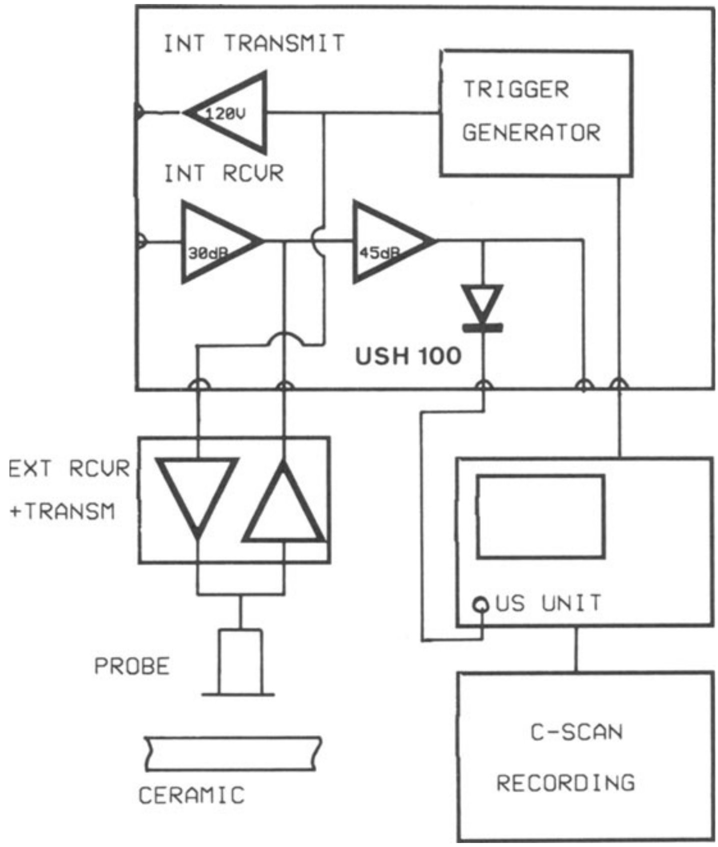

Fig. 3 Schematics of the measuring system

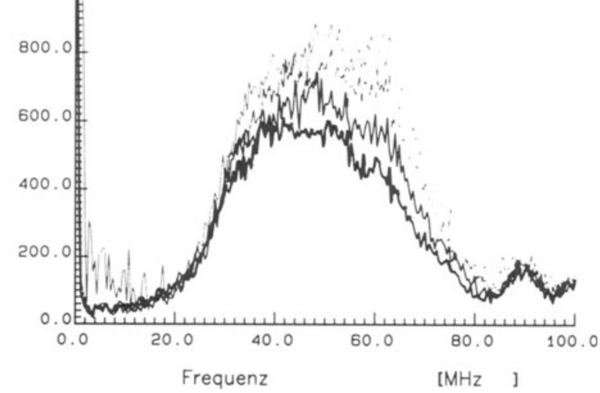

Fig. 4 Frequency dependent absorption in water for different water delays

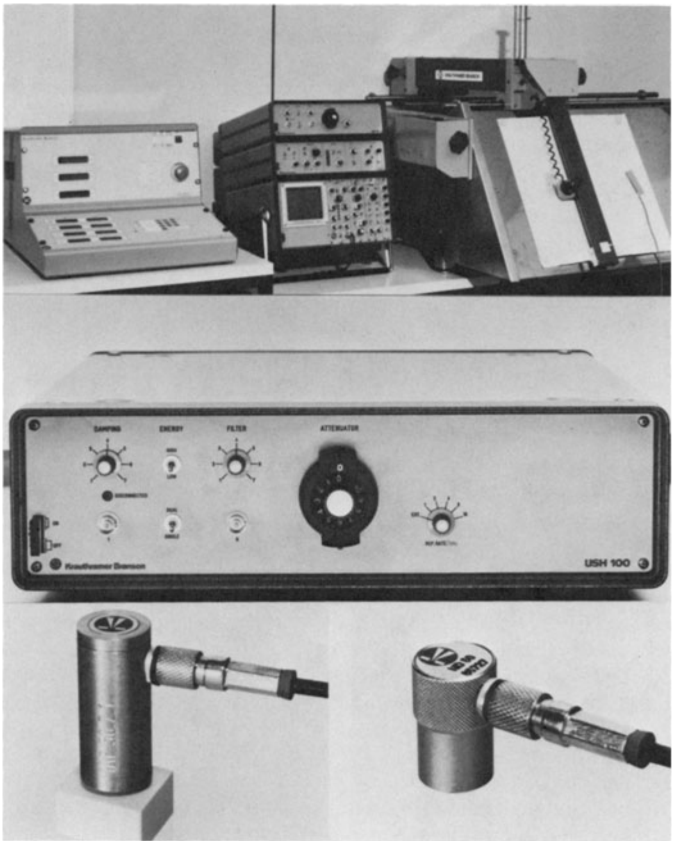

Fig. 5 Hardware used

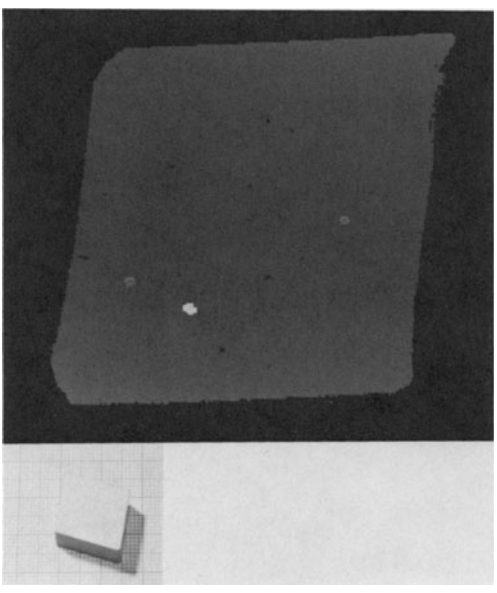

Fig. 6 C-scan plot of a cutting tool

of the transducer is, of course, distorted in the corresponding way and high sensitivity measurements are not possible. This restriction can be overcome by a simple modification of the test setup.

If we use the rectified signal of the high frequency signal (see Fig. 3) instead of the RF-signal then this signal can be processed in a conventional flaw detector, which is usually operated in the 10 to 20 MHz range. In this case the envelope of the US-signal is used, which has a low mean frequency and matches to the frequency range of normal systems.

Nevertheless, the evaluated amplitude is linear and reflects the high frequency sound field of the transducer. The only disadvantage of such a system is that it will not have the resolution in time which could be reached if an overall high frequency system were used.

The basic argumentation for such a system is as follows:

The rectification of a signal is a modulation of the signal with a function which has the value one in the passing time of the rectifier and zero in the closing time. This modulation function has a frequency which corresponds to the mean frequency of the transducer.

A modulation of a signal effects a frequency shift by the amount of the modulation frequency. Thus the high frequency signal of the transducer is shifted down to low frequencies with an upper frequency component corresponding to the band width of the original high frequency signal. The higher side bands of this modulation process are cut off by the limited band width of the flaw detector.

The only frequency effects, which can destroy the high frequency sound field and the detection sensitivity, are frequency dependent absorption in the material and the water delay. In Fig. 4, some measurements with different water delays clearly show frequency dependent absorption. Similar effects can also be seen in powder metals. To take care of these effects only small water delays should be used especially with higher frequencies.

SUMMARY

This is a report on ultrasonic equipment consisting of a focused transducer with suitable transmitter and preamplifier which can operate at test frequencies up to 100 MHz. The equipment (Fig. 5) can be used with conventional flaw detectors and scanning equipment and can detect flaws down to diameters equivalent to 10 micron flat bottom holes in fine ceramics.
Fig. 6 is a C-scan plot of a cutting tool made of fine ceramic where small flaws have been detected.